ON THE PRESENCE OF WATER AT THE ASTEROID 4 VESTA. T. J. Stubbs[1,3,4] and Y. Wang[2,3,4], [1] CRESST, University of Maryland, Baltimore County, Baltimore, MD, [2] GPHI, University of Maryland, Baltimore County, Baltimore, MD, [3] NASA Goddard Space Flight Center, Greenbelt, MD, [4] NASA Lunar Science Institute, Moffett Field, CA. Email: Timothy.J.Stubbs[at]NASA.gov.

Introduction: The presence, or absence, of detectable water on Vesta has important implications for its formation and evolution, its bombardment history, as well as its surface chemistry [1,2,3]. Like the Moon, Vesta is an airless body whose surface regolith is exposed to the harsh space environment. Water, and other volatiles, on the Moon appear to have at least three sources: (1) indigenous, material remaining from the formation process; (2) infall of cometary and chondritic material; and (3) surface chemistry with implanted solar wind ions [1,2]. Although it is unclear which of these sources is dominant [4]. Therefore, the Dawn mission offers an unprecedented opportunity to compare the water/volatile phenomena on the Moon with that on the asteroid Vesta.

We describe the results of a recent study of the average illumination conditions and surface temperatures at Vesta using a modified version of the digital elevation model (DEM) derived from Hubble Space Telescope (HST) images [5,6] together with a sophisticated illumination code and hybrid thermal model [7]. The results of this model suggest that over half of Vesta's surface has an average temperature of < 145 K. For a body like Vesta, which is covered in a dusty regolith [3,8], this suggests that under present-day conditions water ice could survive in the top few meters of the regolith for billions of years [9]. If sufficient water exists in the near-subsurface, then it could be measured by the gamma ray and neutron detector (GRaND) [26]. We also assess the implicatons of some of the early observations from the Dawn mission [8,10] with the results of our modeling.

Water on the Moon: The presence of water in the lunar subsurface has been inferred from the suppression of epithermal neutrons [4,11] and directly measured in the LCROSS impact ejecta plume [12]. Meanwhile, water on the lunar surface has been detected by means of the 2.8 μm and 3μm absorption bands by three different missions [13,14,15], and suggests that hydroxyl and water could be created at the surface by the interaction between solar wind protons and oxygen-bearing minerals [2]. Such water could then possibly migrate to the poles and be sequestered in the cold traps formed by permanently shadowed regions (PSRs) [16,17,18,19]. However, the source of the lunar water still remains far from being well understood, and so comparison with Vesta and elsewhere in the solar system could prove invaluable.

Illumination and Thermal Modeling at Vesta: We note that the basically methodology described in this section could be readily applied to any other airless body in the solar system. See [7] for more information.

Illumination model. In order to produce realsistic results, the HST-based DEM [6] needed to be modified slightly in order to produce realistic illumination predictions. Firstly, we had to smooth out some irregularities near the poles associated with meridional convergence, as opposed to any real topographic features. Secondly, we increased the DEM resolution from 5 × 5° to 1 × 1° using the modified Shepard's method. The illumination code was optimized for speed, accuracy, and versatility by combining aspects of a ray tracing approach and the horizon method [20]. Given the uncertainties in the DEM, we do not consider sunlight scattered from other surface elements, just direct solar illumination. In our simulations we consider the average illumination conditions over one vestal year, which should be indicative of conditions during at least the past few hundred thousand years [21].

Hybrid Thermal Model. When estimating the surface temperatures of asteroids, it has been common to use either the fast-rotating (isothermal latitude) model, which assumes infinite thermal inertia; or the non-rotating (standard thermal) model, which assumes zero thermal inertia. [9]. However, it has recently been demonstated that these two end member thermal models do not produce realistic results when compared with models using a more sophisticated multi-layered treatment of thermal inertia [9]. Therefore, we employed a hybrid thermal model that uses the illumination predictions to estimate the mean dayside temperatures, and assumes a constant mean nightside temperature. The assumptions that the dayside is in thermal equilibrium with the incident solar flux, while the nightside temperature does not vary significantly, is consistent with thermal observations of other airless bodies [19].

We verified this approach by comparing with the results from [9]. The average surface temperature predictions were calculated using the thermal characteristics of Vesta's surface given by [22].

Results: Based on the illumination modeling with the modified HST DEM, we do not expect Vesta to have any significant PSRs under present-day conditions. Using the hybrid thermal model we predict mean surface temperatures ranging from 123.4–150.8 K, with a global annual average of 142.7 K. Therefore, we expect that about 52% of Vesta's surface (around the poles) is cold enough for water ice to have persisted in the top few meters of the regolith for billions of years.

We also assessed the influence of finer scale topography (features < ~100 km) at the location near Vesta's south pole predicted to receive the lowest mean annual solar flux. Finer scale topography was included by convolving a 1 km and 10 km diameter simple lunar crater [23] with the modified HST DEM. Neither a 1 km nor a 10 km diameter crater is able to produce a PSR at this location; although the latter gets very close with average temperatures as low as ~100 K, which is cold enough for water ice to be thermally stable at the surface [17,19]. In both cases there is a large perturbation to the average illumination conditions that produces an overall decrease in surface temperature, which is anticipated to significantly affect the thermal stability of volatiles at the surface, as well as those buried in the regolith.

Disucssion: The depth to which the solar thermal perturbation can penetrate into the regolith can be assessed using the thermal skin depth, which is dependent on the time period of the temperature oscillation [22]. Since Vesta has an obliquity of ≈27.2°, we must consider both the diurnal skin depth (rotation period) near the equator, and the seasonal skin depth (orbital period) near the poles. If water ice does exist in the vestal regolith of the polar regions, then it will likely be at least a few tens of cm below the surface [cf. 22].

The 3 µm absorption feature has also been observed on Vesta [24], but the band depth was only ≈1% which seems too weak to be consistent with the solar wind implantation hypothesis. However, the apparent lack of space weathering on Vesta suggests that it is sufficiently magnetized to be able to shield most of its surface from solar wind protons [e.g., 25]. This proposed proton-shielding could also be the reason for the relatively weak 3 µm absorption feature, and be indicative of lower than expected abundances of hydrated and/or hydroxylated minerals on the surface of Vesta.

Early results from the Dawn mission indicate that the vestal regolith has a low thermal inertia [8], which increases the likelihood that water ice and other volatiles could survive in the subsurface. The regolith on Vesta appears to be exceptionally diverse with regions having received very little space weathering [10]. The less space weathered regions of Vesta's surface could be associated with higher local magnetic fields, which protect it from the solar wind. Conversely, the more weathered regions could be exposed to solar wind protons, and so could permit the formation of hydroxyl and water at the surface.

If the GRaND measurements do not infer any subsurface water ice, then this could be because either it is not present in sufficient quantities, or that it is too deep to be detected. Our predictions were based on present day conditions, and so it is feasible that any subsurface water ice present in the past could have been lost if Vesta had a different orientation, for example.

Conclusions: Based on our illumination and thermal predictions for present day conditions, it is possible that water ice could have survived in the top few meters of the regolith in the polar regions of Vesta for billions of years (over about half of Vesta's surface) should it have been delivered there. As expected, topography plays an important role in determining the average illumination conditions and surface temperatures. In particular, small scale topographic features, such as ~1–10 km diameter craters, can have a significant effect, and perhaps even permit water ice to be thermally stable at the surface (< ~100 K) in some polar locations for much of the vestal year.

References: [1] McCord T.B. et al. (2011) EPSC-DPS2011-567. [2] McCord, T. B., et al. (2011) *JGR*, 116, E00G05. [3] Russell C.T. et al. (2004) *PSS*, 52, 465. [4] Mitrofanov I.G. et al. (2010) Science, 330 483. [5] Thomas P.C. (1997) Science, 277, 1492. [6] Thomas P.C. (1997) Icarus, 128, 88. [7] Stubbs T.J. and Wang Y. (2012) *Icarus*, 217, 272. [8] Capria M.T. et al. (2011) *Fall AGU*, U23B-07. [9] Schorghofer N. (2008) *Astrophys. J.*, 682, 697. [10] Pieters C.M. (2011) *Fall AGU*, U22A-05. [11] Feldman W.C. et al. (1998) *Science*, 281, 1496. [12] Colaprete A., et al. (2010) Science, 330, 463. [13] Clark R.N. (2009) *Science*, 326, 562. [14] Pieters C.M. et al. (2009) *Science*, 326, 568. [15] Sunshine J.M. (2009) *Science*, 326, 565. [16] Schorghofer N. and Taylor G.J. (2007) *JGR*, 112, E02010. [17] Siegler, M.A., et al. (2011), *JGR*, 116, E03010. [18] Crider, D. H. and Killen R. (2005) *GRL*, 32, L12201. [19] Paige D.A. et al. (2010) *Science*, 330, 479. [20] Mazarico E. et al. (2011) *Icarus*, 211, 1066. [21] Bills B.G. and Nimmo F. (2011) *Icarus*, 213, 496. [22] Chamberlain M.A. et al. (2007) *Icarus*, 192, 448. [23] Hörz F. et al. (1991) *Lunar Source Book*, pp. 61. [24] Hasegawa S. et al. (2003) GRL, 30, 2123. [25] Vernazza P. et al. (2006) *Astron. Astrophys.*, 451, L43. [26] Prettyman et al. (2004) *Proc. SPIE*, 5660, 107.